

**Searching for flickering variability in several
symbiotic stars and related objects:
BX Mon, V471 Per, RS Oph, V627 Cas, CI Cam
V886 Her, Z And, T CrB, MWC 560, V407 Cyg***

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ABSTRACT

UBVRI photometry observations of 10 symbiotic stars and related objects obtained in the period 2002-2003 are presented. Analysing differential light curves we found rapid light variations with timescales of tens of minutes and significant amplitudes in the well-known flickerers MWC 560, RS Oph, V407 Cyg and T CrB. MWC 560 and V407 Cyg demonstrate quasi periodic oscillations (QPO) with similar amplitudes and timescales. Flickering and unusual flare in V627 Cas as well as some indications of flickering presence in BX Mon are detected. The existence of 29 minutes oscillations in Z And with an amplitude ~ 0.02 mag in U band is confirmed. Only one symbiotic star, V471 Per, and both non symbiotic, CI Cam and V886 Her seem to be constant on flickering timescales. Nevertheless, small night to night changes in the brightness of V886 Her were observed as well.

1. Introduction

Symbiotic stars are wide binary systems, which generally consist of an active white dwarf and a red giant. The binary is immersed in a nebula formed by the red giant's wind. A part of this matter is accreted by the white dwarf.

*The original differential light curves m_{var} , m_{comp} are available in anonymous ftp at *sirius.astrow.edu.pl*.

The radiation of the hot companion partly ionizes the nebula giving rise to characteristic symbiotic spectrum (highly ionized emission lines superimposed on a cool K-M continuum). Symbiotic binaries show very complex behavior: high and low activity stages, outbursts, jet ejections, eclipses, pulsations of the cool star, etc.

Among about 200 symbiotic stars known, only 8 present rapid variability: RS Oph, T CrB, MWC 560, Z And, V2116 Oph, CH Cyg, RT Cru, o Cet (Belczyński *et al.* 2000, and refs. therein). Recently, V407 Cyg also has been reported as a rapid flickerer in the V light (Kolotilov *et al.* 2003). Most of them show typical flickering i.e. stochastic light variations on timescales from few minutes to more than an hour. The typical flickering amplitude in symbiotic stars is in the range 0.1-0.8 mag. Only Z And presents low-amplitude, strictly coherent variations with a period of about half an hour (Sokoloski *et al.* 1999).

Flickering appears in high activity stage and/or during outbursts. On the other hand, during the eclipse of the hot companion in CH Cyg no flickering has been noticed (Mikołajewski *et al.* 1990; Sokoloski & Kenyon 2003). These facts indicate that the flickering is caused by changes in the surroundings of the compact component. Most of the mentioned 8 stars include a hot component with luminosity $\sim 10\text{--}100 L_{\odot}$. Exceptions are Z And (the hot component luminosity achieves $1000 L_{\odot}$) and V2116 Oph (the hot component is a neutron star).

To explain the flickering origin in low-luminosity symbiotic systems Mikołajewski *et al.* (1996a) adopted the propeller-accretor model (Lipunov 1987). According to this model the flickering results from the interaction of the magnetic white dwarf magnetosphere with the red giant's wind. Recently, three-dimensional MHD simulations for a disc in propeller regime and Bondi accretion confirmed the appearance of quasi-periodic oscillations (QPO) comparable with the observed time-scale (Romanova *et al.* 2003; Romanova *et al.* 2004a). Coherent periodic variations are expected only for a disc in accretor regime (Romanova *et al.* 2004b). This is probably the case of Z And (Sokoloski & Bildsten 1999). On the other hand, (Sokoloski & Kenyon 2003) consider that in the case of CH Cyg the flickering originates in the inner parts of the accretion disk.

In this paper we present and discuss the results from photometric monitoring of 8 symbiotic stars (V407 Cyg, V471 Per, MWC 560, Z And, BX Mon, T CrB, V627 Cas, RS Oph) and of two related objects: the proto-planetary nebula V886 Her and a high mass X-ray Binary CI Cam.

2. Observations and Data Reductions

Present observations have been carried out with the 1.2-m telescope at Kryoneri Astronomical Station of the National Observatory Athens, Greece. The detector was a 516×516 pixels, UV-coated SI-502 CCD Camera with read noise $9.0 e^-$ rms and gain $5.17 e^-/\text{ADU}$. The peltier-cooled to -40 degrees CCD chip gives dark current $1.03 e^-/\text{pix}/\text{s}$. The field of view was relative small, about 2.5×2.5 arcmin and 2×2 binning mode was applied. A standard set of *UBVRI* filters with response curves close to those listed in Bessell (1990) was used.

Typical exposure times were in U : 40-90^s, in B : 20-90^s, in V : 10-40^s, in R : 4-20^s and in I : 1-10^s. The time separation between the measurements in the same filter was in the range of 2.5 - 5 minutes. Standard reduction was preformed with IRAF[†]. Sky-subtracted instrumental magnitudes of target and comparison stars were obtained by means of IRAF task PHOT.

Our observations were restricted by two factors: the weather and the CCD camera small field of view. In the instrumental light curves, besides quadratic trend, a few minima caused by clouds can be seen. Because of this a differential photometry method has been implemented.

The best would be to use the method proposed by Sokoloski *et al.* (2001). They constructed differential light curves by means of artificial standard star, which was made of few stars. We cannot apply the same method because of the small field of view of our camera. Instead, the magnitudes of the target star and of only two brightest field stars were measured. Two differential curves were used for each observation run of each target star. The first one presents the instrumental magnitude difference between the fainter and the brighter comparison stars (thereafter m_{comp}). The second one shows the difference between the target and the brighter comparison instrumental magnitude (m_{var}). The $UB-VRI$ magnitudes of the comparison stars used are taken from Henden & Munari (2000,2001) and (<ftp://ftp.nofs.navy.mil/pub/outgoing/aah>) and are presented in Table 1.

3. Flickering criteria

The standard deviation of the m_{var} light curve is marked as σ_{var} , the standard deviation of the m_{comp} light curve is marked as σ_{comp} . In Table 2 and Table 3 calculated standard deviations and average magnitudes for both types of differential light curves are presented. The number of counts even from the weakest sources were larger than $\sim 10^5$, thus the photon noise (in magnitudes $\sigma \sim N^{-1/2}$) and camera noise ($\sigma \sim N^{-1}$) should be negligible. The relation $\sigma \sim N^{-1/n}$ between our brighter and fainter stars is very poor ($n \gtrsim 8$). A very usefull approximation for large differences between brightnesses gives the equation:

$$\frac{\sigma_{m_1}}{\sigma_{m_2}} = 1 - k(m_2 - m_1), \quad (1)$$

where m_1 and m_2 denote the magnitudes of two stars. Using about 30 pairs of magnitudes in different filters we have found $k = 0.099 \pm 0.009$. The value $k = 0.1$ has been adopted for further calculations. Because of the difference in magnitudes of our variables and comparisons it is necessary to correct the observed σ_{comp} . The new value σ'_{comp} , calculated by the use of Eq. 2, corresponds to the

[†]IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

expected standard deviation of a constant star with the same brightness as the target i.e. $\sigma'_{comp} = \sigma_{comp}(m_{var})$:

$$\sigma'_{comp} = \sigma_{comp}[1 - 0.1(m_{comp} - m_{var})]. \quad (2)$$

This means that if we have an object 5 magnitudes brighter than the comparison a twice smaller standard deviation must be applied to check its variability. The ratio $\sigma_{var}/\sigma'_{comp}$ can define the level of rapid variations of the target star in comparison to the constant star. They are listed in the last five columns of Table 3. Now we can determine the natural criteria for the existence of pronounced variability of the investigated objects:

- (0 σ) $\sigma_{var}/\sigma'_{comp} < 0.5$ - the comparison star is too faint or non constant;
- (1 σ) $0.5 \leq \sigma_{var}/\sigma'_{comp} < 1.5$ - lack of significant variability on measured sensitivity level (possible periodic changes can be reveal);
- (2 σ) $1.5 \leq \sigma_{var}/\sigma'_{comp} < 2.5$ - most probably flickering presents and it is easy to establish if variations are periodic or the changes in the different filters are correlated;
- (3 σ) $2.5 \leq \sigma_{var}/\sigma'_{comp}$ - evident variability with full amplitude about 6 σ_{var} and time scale between the observing run duration and the mean measurements time span.

The expected flickering amplitude can be defined as:

$$A = 6\sqrt{(\sigma_{var})^2 - (\sigma'_{comp})^2}. \quad (3)$$

4. Results

4.1 BX Mon

BX Mon is most probably an eclipsing symbiotic binary with 1401 days period (Dumm *et al.* 1998). The cool component was classified as M5III (Mürset & Schmid 1999). The hot component with mass $\sim 0.6 M_{\odot}$ and luminosity reaching $\sim 230 L_{\odot}$ most probably is a shell flashed white dwarf (Dumm *et al.* 1998).

First attempt to detect flickering was done by Dobrzycka *et al.* (1996) and it was negative. Sokoloski *et al.* (2001) included this object in a list of stars suspected to show flickering activity. BX Mon has been observed only one night. It was about 3 weeks after the mid-eclipse epoch (Dumm *et al.* 1998) and, unfortunately, one month before a significant brightening of about 3 magnitudes in *U* and *B* (Mikołajewski & Gałan, in preparation). The observed by us variations in *BVR* filters (Table 3) fulfil the third of our criteria as defined in Section 3. Moreover, the differential m_{var} light curves in these filters (Fig. 1) show similar shapes that indicate possible variability on timescales of 1-2 hours. Such correlations are not observed in the corresponding m_{comp} light curves. Flickering

Table 1: List of the used comparison stars.

USNO-B1.0	U	B	V	R	I
BX Mon					
0864-0141979	12.770	12.809	12.418	12.158	11.906
0864-0141995	13.523	13.487	12.924	12.572	12.241
V471 Per					
1428-0063362	12.117	12.046	11.479	11.148	10.794
1428-0063398	14.105	12.495	11.030	10.273	9.597
RS Oph					
0833-0368817	17.054	15.969	14.415	13.528	12.645
0833-0368883	17.527	16.826	15.551	14.837	14.110
V627 Cas					
1488-0371126	12.831	12.733	12.103	11.746	11.390
1487-0368382	12.963	12.844	12.323	12.023	11.700
CI Cam					
1460-0131981	15.961	15.332	14.141	13.399	12.608
1460-0132003	17.025	16.539	15.680	15.168	14.607
V886 Her					
1141-0280206	-	13.8 ^a	-	13.1 ^b	12.86 ^c
1141-0280174	-	14.2 ^a	-	13.3 ^b	13.28 ^c
Z And					
1387-0498636	14.820	14.766	14.205	13.868	13.516
1387-0498647	15.237	15.155	14.475	14.042	13.606
T CrB					
1158-0231034	11.946	11.779	11.166	10.766	10.452
MWC 560					
0822-0179335	14.358	12.509	10.784	9.778	8.720
0822-0179227	15.456	14.035	12.668	11.925	11.267
V407 Cyg					
1357-0407034	13.688	13.582	12.908	12.522	12.141
1357-0407056	12.969	12.857	12.233	11.885	11.541

^a B magnitude from USNO-A2.0 catalog;^b R magnitude from USNO-A2.0 catalog;^c I magnitude from USNO-B1.0 catalog.

Table 2: Averages and standard deviations of m_{var} differential light curves.

Object/Data	JD	Duration [h]	Number	U_{var}	σ_{var}^U	B_{var}	σ_{var}^B	V_{var}	σ_{var}^V	R_{var}	σ_{var}^R	I_{var}	σ_{var}^I
BX Mon													
16/03/2002	2452350	5.8	96	-0.484	0.030	-0.252	0.016	-0.857	0.011	-1.756	0.008	-3.168	0.007
V471 Per													
24/11/2002	2452603	1.4	50	2.036	0.016	1.926	0.009	1.622	0.006	1.235	0.006	1.118	0.007
25/11/2002	2452604	0.7	15	2.029	0.028	1.939	0.014	1.643	0.038	1.250	0.027	1.132	0.030
RS Oph													
16/06/2002	2452442	0.8	20	-	-	-3.445	0.057	-3.254	0.033	-3.339	0.024	-3.491	0.022
27/08/2002	2452514	1.8	32	-	-	-3.110	0.047	-3.087	0.028	-3.251	0.019	-3.436	0.014
V627 Cas													
28/08/2002	2452515	5.8	96	-	-	1.980 ^a	0.016 ^a	0.383	0.006	-1.238	0.012	-3.296	0.017
CI Cam													
24/11/2002	2452603	1.5	25	-3.872	0.052	-2.919	0.016	-2.567	0.012	-2.723	0.015	-2.853	0.015
25/11/2002	2452604	1.6	30	-3.837	0.044	-2.860	0.023	-2.530	0.014	-2.678	0.014	-2.833	0.012
V886 Her													
15/06/2002	2452441	1.9	30	-3.580	0.014	-2.392	0.007	-1.739	0.007	-1.370	0.007	-0.914	0.006
16/06/2002	2452442	1.5	30	-3.671	0.012	-2.475	0.007	-1.802	0.006	-1.432	0.006	-0.975	0.007
20/06/2002	2452446	2.2	25	-3.670	0.013	-2.472	0.008	-1.786	0.004	-1.401	0.005	-0.922	0.005
Z And													
15/06/2002	2452441	1.1	24	-4.243	0.025	-3.605	0.013	-3.909	0.011	-4.651	0.016	-	-
29/09/2002	2452547	3.9	86	-3.942	0.013	-3.580	0.012	-3.922	0.012	-4.690	0.015	-	-
T CrB													
14/03/2002	2452348	2.5	41	0.535	0.074	-0.446	0.016	-1.149	0.016	-1.863	0.012	-3.232	0.010
15/03/2002	2452349	4.4	52	0.427	0.083	-0.466	0.016	-1.171	0.018	-1.877	0.014	-3.234	0.017
16/03/2002	2452350	2.4	17	0.218	0.058	-0.508	0.032	-1.183	0.022	-1.893	0.022	-3.247	0.021
MWC 560													
15/03/2002	2452349	3.8	102	-	-	-1.117	0.094	-0.183	0.076	0.065	0.043	-0.480	0.014
23/11/2002	2452602	2.1	55	-3.540	0.146	-1.362	0.123	-0.300	0.120	0.039	0.079	-0.342	0.021
24/11/2002	2452603	3.5	80	-3.362	0.087	-1.217	0.068	-0.158	0.061	0.138	0.040	-0.325	0.014
25/11/2002	2452604	3.3	84	-3.499	0.102	-1.433	0.086	-0.363	0.074	-0.000	0.054	-0.351	0.020
29/11/2002	2452608	5	150	-3.583	0.086	-1.421	0.063	-0.360	0.061	-0.008	0.044	-0.365	0.016
30/11/2002	2452609	3.3	100	-3.568	0.102	-1.375	0.082	-0.326	0.075	0.027	0.054	-0.353	0.026
V407 Cyg													
29/11/2002	2452608	3.3	80	1.935	0.132	2.046	0.141	1.648	0.140	0.212	0.054	-2.772	0.016
11/06/2003	2452802	4.7	100	1.059	0.088	0.844	0.064	-0.076	0.042	-1.631	0.020	-4.143	0.019
12/06/2003	2452803	5.2	120	1.133	0.070	0.874	0.050	-0.067	0.030	-1.647	0.017	-4.170	0.023
13/06/2003	2452804	5.3	130	1.109	0.088	0.853	0.058	-0.084	0.034	-1.667	0.016	-	-
14/06/2003	2452805	5.8	150	1.097	0.065	0.817	0.046	-0.107	0.028	-1.665	0.013	-	-
03/07/2003	2452824	5.3	135	1.390	0.043	0.853	0.019	-0.284	0.010	-1.882	0.008	-	-
04/07/2003	2452825	4.6	120	1.355	0.034	0.824	0.017	-0.318	0.012	-1.910	0.010	-	-
05/07/2003	2452826	4.2	110	1.286	0.044	0.781	0.017	-0.358	0.012	-1.938	0.009	-	-
06/07/2003	2452827	3.4	90	1.216	0.022	0.733	0.013	-0.395	0.008	-1.964	0.008	-	-

^a The flare was excluded.

Table 3: Averages and standard deviations of m_{comp} differential light curves. In the last five columns the ratio $\sigma_{var}/\sigma'_{comp}$ is shown.

Object/Data	U_{comp}	σ_{comp}^U	B_{comp}	σ_{comp}^B	V_{comp}	σ_{comp}^V	R_{comp}	σ_{comp}^R	I_{comp}	σ_{comp}^I	U	$\frac{\sigma_{var}/\sigma_{comp}}{1-0.1(m_{comp}-m_{var})}$			
												B	V	R	I
BX Mon															
16/03/2002	0.751	0.053	0.639	0.010	0.517	0.007	0.418	0.007	0.325	0.009	0.645	1.756	1.822	1.460	1.195
V471 Per															
24/11/2002	1.873	0.015	0.340	0.006	-0.397	0.005	-0.821	0.005	-1.237	0.006	1.049	1.294	0.998	0.995	0.944
25/11/2002	1.853	0.053	0.312	0.031	-0.401	0.005	-0.828	0.012	-1.249	0.017	0.519	0.388	6.310	1.863	1.425
RS Oph															
16/06/2002	-	-	0.906	0.027	1.144	0.015	1.307	0.020	1.527	0.029	-	3.737	3.927	2.241	1.522
27/08/2002	-	-	0.916	0.018	1.144	0.013	1.303	0.017	1.532	0.026	-	4.371	3.733	2.052	1.070
V627 Cas															
28/08/2002	-	-	0.137	0.005	0.214	0.004	0.264	0.010	0.315	0.016	-	2.702	1.475	1.412	1.663
CI Cam															
24/11/2002	1.072	0.155	1.229	0.038	1.509	0.025	1.733	0.017	2.112	0.114	0.664	0.720	0.810	1.592	0.261
25/11/2002	1.082	0.100	1.252	0.028	1.533	0.019	1.761	0.027	2.065	0.048	0.866	1.395	1.241	0.932	0.490
V886 Her															
15/06/2002	1.109	0.024	0.861	0.010	0.677	0.005	0.571	0.007	0.396	0.005	1.098	1.037	1.846	1.241	1.381
16/06/2002	1.107	0.024	0.847	0.010	0.672	0.009	0.569	0.008	0.396	0.006	0.957	1.048	0.886	0.938	1.352
20/06/2002	1.112	0.033	0.843	0.007	0.663	0.006	0.544	0.005	0.379	0.007	0.755	1.710	0.883	1.241	0.821
Z And															
15/06/2002	0.428	0.038	0.379	0.027	0.275	0.013	0.182	0.024	-	-	1.235	0.800	1.455	1.290	-
29/09/2002	0.427	0.024	0.385	0.012	0.274	0.010	0.190	0.018	-	-	0.962	1.657	2.068	1.628	-
MWC 560															
15/03/2002	-	-	1.603	0.015	1.814	0.010	2.147	0.013	2.608	0.014	-	8.608	9.496	4.177	1.447
23/11/2002	1.305	0.075	1.570	0.009	1.864	0.006	2.109	0.006	2.598	0.012	3.776	19.336	25.523	16.604	2.479
24/11/2002	1.229	0.074	1.563	0.016	1.851	0.016	2.106	0.021	2.586	0.018	2.174	5.886	4.771	2.371	1.097
25/11/2002	1.374	0.109	1.617	0.016	1.871	0.010	2.129	0.010	2.602	0.012	1.825	7.734	9.529	6.861	2.365
29/11/2002	1.279	0.055	1.592	0.010	1.884	0.009	2.134	0.011	2.596	0.013	3.043	9.017	8.739	5.090	1.749
30/11/2002	1.326	0.046	1.640	0.017	1.898	0.016	2.148	0.021	2.613	0.022	4.343	6.906	6.028	3.264	1.680
V407 Cyg															
29/11/2002	0.725	0.017	0.720	0.006	0.687	0.007	0.629	0.007	0.583	0.016	6.927	20.749	18.247	8.050	1.505
11/06/2003	0.723	0.012	0.717	0.007	0.682	0.006	0.649	0.010	0.593	0.015	7.095	9.028	7.574	2.591	2.406
12/06/2003	0.724	0.015	0.716	0.010	0.678	0.010	0.645	0.013	0.590	0.026	4.483	4.922	3.241	1.697	1.688
13/06/2003	0.726	0.018	0.716	0.013	0.685	0.011	0.641	0.012	-	-	4.709	4.401	3.348	1.733	-
14/06/2003	0.723	0.016	0.720	0.010	0.688	0.008	0.642	0.009	-	-	3.916	4.556	3.802	1.878	-
03/07/2003	0.727	0.011	0.723	0.006	0.688	0.005	0.640	0.007	-	-	3.666	3.126	2.215	1.528	-
04/07/2003	0.732	0.011	0.724	0.008	0.693	0.009	0.647	0.011	-	-	2.910	2.104	1.483	1.221	-
05/07/2003	0.729	0.010	0.722	0.006	0.685	0.006	0.648	0.009	-	-	4.168	2.817	2.233	1.348	-
06/07/2003	0.727	0.011	0.720	0.007	0.688	0.008	0.643	0.007	-	-	1.907	1.855	1.121	1.545	-

variability in BX Mon is possible, however new observations, especially during outbursts are needed.

4.2 *V471 Per*

V471 Per belongs to the small group of yellow symbiotic stars. Such systems have cool companion of F, G, K or early R spectral type (Mikołajewska 1997). The spectral type of the V471 Per cool component is G5II (Belczyński *et al.* 2000). The nature of its hot component is unknown.

An attempt to detect flickering in V471 Per was made by Sokoloski *et al.* (2001) and the result was negative. Our observations of this star were carried out during two nights. During the first night the $\sigma_{var}/\sigma'_{comp}$ ratio is close to 1 in all filters and m_{var} light curves show no variability (Fig. 2).

The observations during the second night formally show detection of flickernig in the *V* filter: $\sigma_{var}/\sigma'_{comp} = 6.3$ (Table 3). However, the observing run was very short (15 points in 32 minutes) and additionally the weather conditions were not good close to the end of this run when the detected variations apeared (Fig. 2). No corelation between the light-curve changes in the different filters were observed. Concluding, this detection is very questionable.

4.3 *RS Oph*

RS Oph is one of the four recurrent novae among the symbiotic stars (Anupama & Mikołajewska 1999). The cool component is a K7III star (Mürset & Schmid 1999) while the hot one is a white dwarf with luminosity $\sim 100 L_{\odot}$ (Snijders 1987). Nova-like outbursts observed in this system have been reported (Allen 1984; Kenyon 1986; Sanduleak & Stephenson 1973; Schaefer 2004). Flickering in RS Oph has been known since fifties. Rapid light variation with amplitude ~ 0.3 mag in RS Oph were reported by Walker (1957), Walker (1977), Bruch (1980,1992). Brightness variations on a timescale of about 80 minutes was found by Dobrzycka *et al.* (1996).

We observed RS Oph during two nights. In both cases the duration of the observations was comparable with the typical timescale of the flickering in this system. A strong linear decrease is evident in the m_{var} differential light curves (Fig. 3). Theirs slopes on 27 August 2002 were 0.16, 0.10, 0.08, 0.05 mag in *BVRI* filters respectively. Despite the very short duration of our observations on 16 June the slopes are even greater. However, the *I* band inversed slopes of m_{var} and m_{comp} curves (Fig. 3) can be connected with the second-order atmospheric extinction. The existence of short time variability in *BV* is evident also in the sense of our criterion (3σ).

4.4 *V627 Cas*

V627 Cas has been initially classified as T Tau variable (Paupers *et al.* 1989), whereas Kolotilov (1998) proposed its symbiotic nature. It was included in the Belczyński *et al.* (2000) list of stars suspected to be symbiotic. The spectral

type of the cool component is M2-4II (Kolotilov *et al.* 1991). Pulsations with a period of ~ 466 days and brightness changes from night to night, indicating possible presence of flickering, were reported by Kolotilov *et al.* (1991,1996). It has been suggested that the V627 Cas hot companion activity is of similar nature as that of CH Cyg.

Kolotilov *et al.* (1991) also observed short-living flares with amplitude of about 0.5 magnitudes in B . A similar phenomenon was registered in our data. A flickering-like flare with amplitude ~ 0.1 mag and duration ~ 30 minutes in B is evident on August 28 whereas in the other bands (VRI) no such brightness changes were noticed (Fig. 4). The ratio $\sigma_{var}/\sigma'_{comp}$ is about 2.7 in B (the flare excluded) and ~ 1.5 in the other bands (Table 3). The lack of flares in the other filters can be caused by the significant cool component contribution. Additionally, a weak linear trend with decreasing rate of 0.01 mag per hour is evident in the m_{var} differential light curve in B . Similar but smaller slopes in m_{var} are visible in the other filters as well (Fig. 4). Such linear trends can reflect night to night brightness changes on time scales few times longer than the typical flickering ones.

4.5 CI Cam

CI Cam is a high mass X-ray binary which includes a B[e]II star as a mass donor. The nature of the compact star is unclear. However, $L(2-25\text{keV}) > 3 \times 10^{38} \text{ ergs s}^{-1}$ is typical for a binary with a black hole component but, there are no mass estimations of the compact object (Robinson *et al.* 2002). A strong outburst occurred in March 1998 and CI Cam became the brightest object in X-rays on the whole sky. It was two times brighter than Crab (Smith *et al.* 1999). Five days later Hjellming & Mioduszewski (1998a,b) observed appearance of radio jets with velocity of $0.15 c$. Before the outburst, Bergner *et al.* (1995) speculated about symbiotic nature of CI Cam.

Flickering in this system has been never detected. One negative attempt was made by Belloni *et al.* (1999). Our observations show $\sigma_{var}/\sigma'_{comp}$ less than 1 for almost all filters (Table 3) i.e. lack of flickering with amplitude larger than 0.04-0.05 for U and 0.01-0.02 for $BVRI$ bands (Table 2).

4.6 V886 Her

V886 Her = IRAS 18062+2410 was classified as a proto-planetary nebula and its mass was estimated to $0.7 \pm 0.01 M_{\odot}$ (Arkhipova *et al.* 1996). The star's spectral type changes relatively fast. From A5, as listed in the HDE catalog, to B5I or B1-2II estimated by Arkhipova *et al.* (1996, 1999). V886 Her is a Be star with strong $H\alpha$ ($EW \approx 20 \text{ \AA}$) and other Balmer and strong oxygen OI $\lambda 8446 \text{ \AA}$ emission lines. Arkhipova *et al.* (1999) found that V886 Her is embedded in a dust envelope with a temperature about 220 K.

Brightness variations with an amplitude of 0.4 mag and timescales from a day to a week has been observed in 1995 (Arkhipova *et al.* 1996). Gauba & Parthasarathy (2003) noticed changes in the UV (IUE) flux during three years.

Our observations of V886 Her cover three nights. We did not find clear evidences of flickering but weak linear trends in U , B and R of 0.005-0.01 magnitudes per hour are present (Fig. 5). These trends can explain the small changes of the mean brightness from night to night up to 0.09 magnitudes in U , 0.08 in B and about 0.06 in VRI that were observed as well.

4.7 Z And

Z And is a prototype of symbiotic star and is one of the most intensively studied. The spectral type of the cool component is M4.5III (Mürset & Schmid 1999) whereas the companion is a hot white dwarf ($T_{\text{eff}} \sim 10^5$ K) with luminosity ~ 500 -2000 L_{\odot} (Viotti *et al.* 1982; Kenyon & Webbink 1984; Fernández-Castro *et al.* 1988; Mürset *et al.* 1991). A stable nuclear burning of accreted matter on the compact component surface is considered as the most probable energy source. Sporadic changes in the accretion rate cause irregular outbursts with an amplitude of about 2-3 mag (Mikolajewska & Kenyon 1992).

The orbital period of Z And is 759 days (Formigini & Leibowitz 1994; Mikolajewska & Kenyon 1996). The inclination angle estimated on the base of polarimetric observations is 45 ± 12 degree which gives for the mass of the white dwarf $0.65 \pm 0.28 M_{\odot}$ (Schmid & Schild 1997). Possible radio jets emission has been reported by (Brocksopp *et al.* 2004).

No evidence of classical, stochastic flickering has been noticed in several sets of long-term monitoring of Z And (Walker 1957; Belyakina 1965; Dobrzycka *et al.* 1996). For the first time, during the 1997 outburst, Sokoloski & Bildsten (1999) reported the presence of strictly periodic rapid light variability, shortly after the maximum (Fig. 6). Contrary, during the quiescence (\sim JD 24501000) no rapid variations were presented.

Our observations cover two nights. In both cases $\sigma_{\text{var}}/\sigma'_{\text{comp}} \leq 1.5$ indicates no flickering. However, the detection level was about 0.011-0.025 magnitude (Table 3) i.e. few times larger than the above mentioned amplitude of periodic oscillations. Following Sokoloski & Bildsten (1999), we tried to search for periodicity in the pure instrumental data after quadratic trend (air mass changes) removing. The Fourier analysis (Fig. 7) of such light curves from the second night (when the weather conditions were pretty good) reveals ~ 29 minutes period in U , very close to that found by Sokoloski & Bildsten (1999). The folded light curve with this period (1781 sec) is shown in the bottom panel of Fig. 7. The amplitude in U is about 0.02 magnitude. Our observations were carried out just before and just after a short, deep minimum during the 2000-2003 outburst (Fig. 6). Skopal (2003) interpreted this minimum as an eclipse of the hot component. The UBV brightnesses of Z And at the moments of our observations and the observations of Sokoloski & Bildsten (1999) during the previous outburst are similar (Fig. 6). They discovered coherent oscillations in B filter with a period 28 min and an amplitude about 3 mmag. Our oscillations in U filter show almost the same period and an amplitude about 15-20 mmag, i.e. about 5-7 times larger than the previously observed in B . Suggesting that the rapid variations in U and B have the same origin, the amplitude difference argues the

higher contribution of the oscillations source towards the short wavelengths.

4.8 *T CrB*

T CrB is another recurrent nova among the symbiotic stars. Two outbursts in this system were observed in 1866 and 1946 (e.g. Belczyński & Mikołajewska 1998). In quiescence the system reveals an ellipsoidal variability with a period of ~ 228 days. This fact suggests that the cool component almost fills up its Roche lobe. The spectral type of the cool star is M4III (Mürset & Schmid 1999). The white dwarf luminosity is $\sim 5-40 L_{\odot}$ (Cassatella *et al.* 1982,1985; Selvelli *et al.* 1992). For a long time there was a controversy concerning T CrB because the compact component mass estimations exceeded the Chandrasekhar limit (Kraft 1958; Paczyński 1965; Kenyon & Garcia 1986). Belczyński & Mikołajewska (1998) lowered this mass to the range $1.2-1.4 M_{\odot}$. Recently, Stanishev *et al.* (2004) analyzing H_{α} observations of T CrB obtained during the last decade, found an orbital inclination $i=67^{\circ}$ and components mass $M_{WD}=1.37\pm 0.13 M_{\odot}$ and $M_{RG}=1.12\pm 0.23 M_{\odot}$.

Strong flickering in *U* with amplitude of 0.1-0.5 has been known in T CrB since long time (Ianna 1964; Lawrence *et al.* 1967; Bianchini & Middleditch 1976; Sokoloski *et al.* 2001; Zamanov *et al.* 2004). In *B* and *V* the flickering amplitude is smaller (Raikova & Antov 1986; Hric *et al.* 1998). However, observations with no flickering detection has been reported as well (Bianchini & Middleditch 1976; Oskanian 1983; Dobrzycka *et al.* 1996; Mikołajewski *et al.* 1997).

Because of the small field of view, during the three nights of our monitoring, we observed T CrB and the comparison star alternatively, on different CCD frames. The brightness of the comparison star was interpolated to the observation time of T CrB and only m_{var} differential light curves were obtained. In these curves relatively high amplitude rapid brightness variations and up to ~ 0.2 mag night to night changes of the mean brightness are evident only in *U*. Therefore, our results confirm the cited above that, when presented in T CrB, the flickering is best visible in *U* band.

4.9 *MWC 560*

MWC 560 is one of the most enigmatic symbiotic systems with spectacular jets ejected along the line of sight (Tomov *et al.* 1990). The spectral type of the cool component is M4-6III (Thakar & Wing 1992; Zhekov *et al.* 1996; Mürset & Schmid 1999). Depending on the activity stage the luminosity of the white dwarf was estimated to $\sim 100-1000 L_{\odot}$ (Tomov *et al.* 1996; Mikołajewski *et al.* 1998).

The first detection of flickering has been reported by Bond *et al.* (1984). Since 1990, when the systematic investigation of MWC 560 began, many authors observed flickering with amplitudes in the range 0.2-0.7 mag (Michalitsianos *et al.* 1993, Tomov *et al.* 1996; Dobrzycka *et al.* 1996; Mikołajewski *et al.* 1998; Ishioka *et al.* 2001; Sokoloski *et al.* 2001).

Our observations of MWC 560 include six nights. The ratios $\sigma_{var}/\sigma'_{comp}$ together with roughly the same light curves shape in all bands indicate presence of flickering in all nights. As an example the differential light curves for two nights are presented in Fig 9.

Fourier analysis (Deeming 1975) of the MWC 560 differential light curves do not show significant frequency peaks in the power spectra of m_{comp} . Rather, a typical noise spectrum is seen. Contrary, the power spectra of m_{var} light curves are dominated by low frequency peaks corresponding to periods in the range from 30 to 100 minutes. The shape of the power spectra changes from night to night. An analysis of combined data set (23, 24, 25, 29, and 30 November) do not show coherent variations. The power spectra are dominated by low frequency peaks with periodicity of ~ 2 hours, ~ 70 , ~ 50 minutes (see Fig. 10). The residuals of the light curves folded with these periods are presented in Fig. 11. The period ~ 70 minutes corresponds to the sharp maximum of possible quasi-periods found by Tomov *et al.* (1996) in almost fifty different runs of flickering monitoring. Regular, sinusoidal variations with amplitude larger than $\pm 3\sigma$ in *UBVR* (Fig. 11) demonstrates only the mean light curve with ~ 70 minutes period ($P = 4241$ sec). Moreover, Mikołajewski *et al.* (1996b), on data obtained also with the 1.2m Kryoneri telescope during four nights of January 1993, estimated almost the same frequency ($P = 4225.3$ sec). It is rather difficult to argue about the coherence of the variations with this period, however, the power spectra suggest that such variations can appear and disappear. So, they should be classified rather as a kind of quasi periodic oscillations (QPO).

4.10 V407 Cyg

V407 Cyg is a symbiotic system which includes a low luminosity white dwarf and a Mira with the longest known among the symbiotics pulsation period of 763 days. The luminosity of the hot component is ~ 100 -400 L_{\odot} depending on the stage of activity (Kolotilov *et al.* 2003; Tatarnikova *et al.* 2003). The spectrum is usually dominated by absorption features, originating in the cool component atmosphere. Emission lines typical for a symbiotic system are sporadically observed. For the first time a symbiotic spectrum was observed in 1994 (Kolotilov *et al.* 1998). Rapid photometric variability in V was detected in June 2002 (Kolotilov *et al.* 2003). The variations amplitude was 0.2 mag and Fourier analysis showed two periods: 18 and 33 minutes.

The observations of V407 Cyg were secured during one night in November 2002, four consecutive nights in June 2003 and four consecutive nights in July 2003. At that time the outburst which has began in 1998 (Kolotilov *et al.* 2003; Tatarnikova *et al.* 2003) still continued. After the third night we stopped the observations in *I* band because Mira was too bright being in maximum. Examples of differential light curves are presented in Fig. 12. The corrected ratio $\sigma_{var}/\sigma'_{comp}$ indicates the permanent presence of flickering in *UBV* and far from the Mira maximum also in *R*.

The Fourier analysis (Deeming 1975) of V407 Cyg differential light curves shows results similar to those of MWC 560. The m_{var} light curves power spectra

in *UBVR* are very similar and are dominated by low frequency peaks corresponding to periods in the range from 30 to about 100 minutes. Contrary, the power spectra of m_{var} in *I* do not show significant frequency peaks, suggesting that the *I* flux is dominated by Mira and there is no evident flickering. Two data sets, each combined by the observations in four consecutive nights (June and July 2003) were analyzed as well. The power spectra of the combined data are dominated by low frequency peaks corresponding to periods of ~ 2 hours, ~ 72 and ~ 45 minutes (Fig. 13). As it can be seen in Fig. 13 significant night to night variations in the peaks are evident. Obviously, the rapid variations in the brightness of V407 Cyg are not coherent. Most probably these are QPO like the observed in MWC 560.

5. Concluding remarks

In this paper we present results of one of the most extensive surveys searching for flickering in symbiotic stars and related objects. Two earlier surveys had been published by Dobrzycka *et al.* (1996) and Sokoloski *et al.* (2001). Most of the previous flickering observations were made in one band only, usually in *U* or *B*. We observed in five filters (*UBVRI*) allowing us to obtain more detailed information about the contribution of the flickering source to the symbiotic spectrum. Our results are summarized in Table 4, where the flickering amplitudes are calculated using Equation (3) and assuming corrected σ'_{comp} as their error.

We found that the flickering is presented in almost all bands in the symbiotic systems MWC 560, RS Oph and V407 Cyg. This proves that here the contribution of the hot component to each particular band is sufficient. Another symbiotic star with similar flickering characteristics is CH Cyg (Mikołajewski *et al.* 1990). The variations timescales and amplitudes in these four systems show close resemblance and indicate a stochastic nature. In particular nights, quasi-periodic oscillations with periods from several minutes to more than one hour can dominate the light curve. The QPO are not coherent from night to night and over longer periods, and vary in amplitude and phase. Typical properties of these four stars are a low-luminosity hot component and permanent or occasional jets ejection. The common observational characteristics of the flickering and the physical properties of these objects point to a similar flickering generation mechanism.

It seems that T CrB should also be included in this group of stars, but its low activity during our observation run allowed to detect flickering in *U* band only. The symbiotic star V627 Cas, seems also to contain a low-luminosity hot component. At least two types of variability are evident in our observations: short-living flickering-like flares and night to night changes. We cannot exclude the existence of flickering in BX Mon. The differential light curves in *U* and *R* show almost the same shapes as in *BV*, where $\sigma_{var}/\sigma'_{comp}$ are greater than 1.5, satisfying our criterion (2σ).

Unlike the above stars, Z And is a classical symbiotic system with a high luminosity hot component during outbursts. Rapid variability was undoubtedly

observed in this system by Sokoloski & Bildsten (1999), but only in B . It showed low amplitude (0.002-0.005 mag) and strictly periodic variations, and probably lack of stochastic changes. This result was interpreted as caused by the rotation of the magnetic white dwarf component. There are not known coherent periodicities in other symbiotic systems. We found the same periodicity during another outburst and with another filter. The variations here have amplitude of about 0.02 magnitudes in U , i.e. several times larger than previously observed in B .

Among the observed symbiotic stars only V471 Per seems to be constant on short time scales. We also did not find rapid variability in CI Cam and V886 Her, the two not symbiotic objects among our targets. However, the central star of the protoplanetary nebula, V886 Her, shows different magnitudes from night to night in $UBVRI$ indicating a long-term variability with amplitude of about 0.1 magnitude.

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Table 4: Flickering amplitudes in different filters estimated according Eq. 3. As errors the σ'_{comp} values are assumed. The amplitudes derived from the data satisfying our criterion (1σ) are shown in brackets, because they are probably not real.

Object/Data	A_U	A_B	A_V	A_R	A_I
BX Mon					
16/03/2002	-	0.079 ± 0.009	0.055 ± 0.006	(0.035 ± 0.005)	(0.023 ± 0.006)
V471 Per					
24/11/2002	(0.029 ± 0.015)	(0.034 ± 0.007)	-	-	-
25/11/2002	-	-	0.225 ± 0.006 :	0.137 ± 0.014 :	(0.128 ± 0.021)
RS Oph					
16/06/2002	-	0.330 ± 0.015	0.191 ± 0.008	0.129 ± 0.011	0.100 ± 0.014
27/08/2002	-	0.275 ± 0.011	0.162 ± 0.007	0.100 ± 0.009	(0.030 ± 0.013)
V627 Cas					
28/08/2002	-	0.089 ± 0.006	(0.026 ± 0.004)	(0.051 ± 0.008)	0.081 ± 0.010
CI Cam					
24/11/2002	-	-	-	0.070 ± 0.009 :	-
25/11/2002	-	(0.096 ± 0.016)	(0.050 ± 0.011)	-	-
V886 Her					
15/06/2002	(0.035 ± 0.013)	(0.011 ± 0.007)	0.035 ± 0.004	(0.025 ± 0.006)	(0.025 ± 0.004)
16/06/2002	-	(0.013 ± 0.007)	-	-	(0.028 ± 0.005)
20/06/2002	-	0.039 ± 0.005	-	(0.018 ± 0.004)	-
Z And					
15/06/2002	(0.088 ± 0.020)	-	(0.048 ± 0.008)	(0.061 ± 0.012)	-
29/09/2002	0.020 ± 0.003^a	0.057 ± 0.007 :	0.063 ± 0.006 :	0.071 ± 0.009 :	-
T CrB					
15/06/2002	0.32 ± 0.05^b	-	-	-	-
16/06/2002	0.39 ± 0.05^b	-	-	-	-
20/06/2002	0.18 ± 0.05^b	-	-	-	-
MWC 560					
15/03/2002	-	0.560 ± 0.011	0.453 ± 0.008	0.250 ± 0.010	(0.061 ± 0.010)
23/11/2002	0.845 ± 0.039	0.737 ± 0.006	0.719 ± 0.005	0.473 ± 0.005	0.115 ± 0.008
24/11/2002	0.463 ± 0.040	0.402 ± 0.012	0.358 ± 0.013	0.218 ± 0.017	(0.035 ± 0.013)
25/11/2002	0.512 ± 0.056	0.512 ± 0.011	0.442 ± 0.008	0.321 ± 0.008	0.109 ± 0.008
29/11/2002	0.487 ± 0.028	0.376 ± 0.007	0.364 ± 0.007	0.259 ± 0.009	0.079 ± 0.009
30/11/2002	0.596 ± 0.023	0.487 ± 0.012	0.444 ± 0.012	0.308 ± 0.017	0.125 ± 0.015
V407 Cyg					
29/11/2002	0.784 ± 0.019	0.845 ± 0.007	0.839 ± 0.008	0.321 ± 0.007	0.072 ± 0.011
11/06/2003	0.523 ± 0.012	0.382 ± 0.007	0.250 ± 0.006	0.111 ± 0.008	0.104 ± 0.008
12/06/2003	0.409 ± 0.016	0.294 ± 0.010	0.171 ± 0.009	0.082 ± 0.010	0.111 ± 0.014
13/06/2003	0.516 ± 0.019	0.339 ± 0.013	0.195 ± 0.010	0.078 ± 0.009	-
14/06/2003	0.377 ± 0.017	0.269 ± 0.010	0.162 ± 0.007	0.066 ± 0.007	-
03/07/2003	0.248 ± 0.012	0.108 ± 0.006	0.054 ± 0.005	0.036 ± 0.005	-
04/07/2003	0.192 ± 0.012	0.090 ± 0.008	(0.053 ± 0.008)	(0.034 ± 0.008)	-
05/07/2003	0.256 ± 0.011	0.095 ± 0.006	0.064 ± 0.005	(0.036 ± 0.007)	-
06/07/2003	0.112 ± 0.012	0.066 ± 0.007	(0.022 ± 0.007)	0.037 ± 0.005	-

^a amplitude defined as the difference between maximum and minimum of the mean light curve with period $P=1781s$ (Fig. 7).

^b $\sigma'_{comp} = 0.05$ was adopted.

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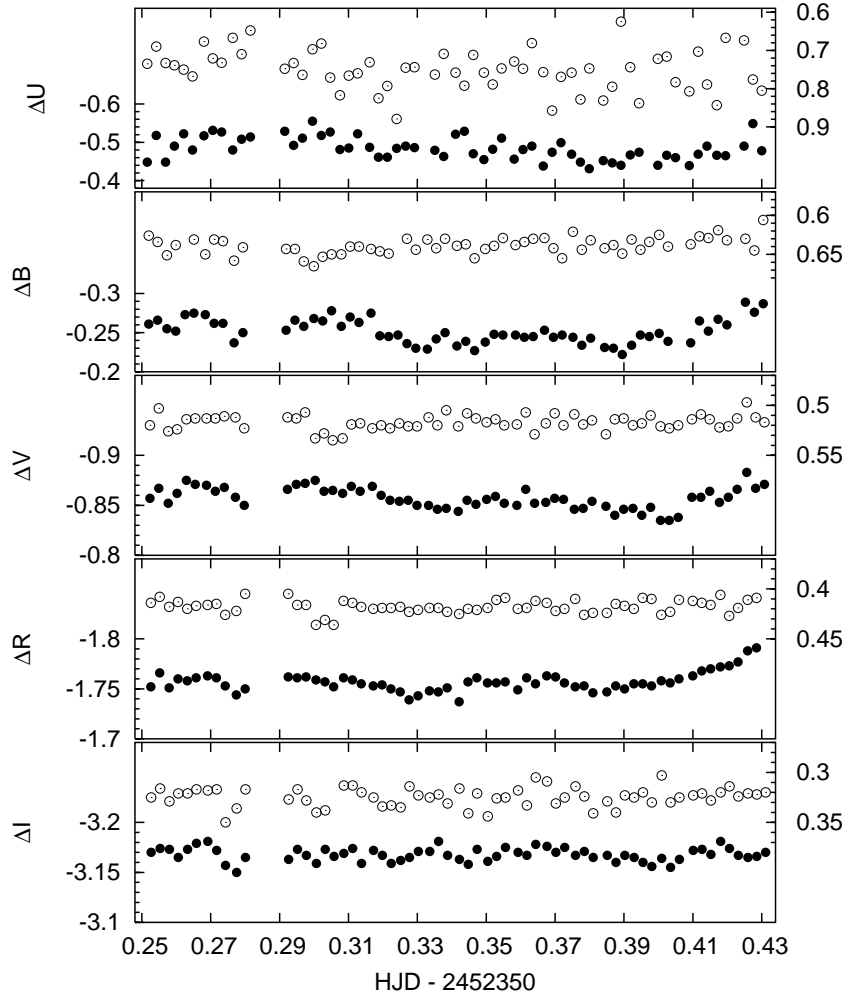


Figure 1: Differential light curves m_{var} (dots) and m_{comp} (open circles) for BX Mon on 16 March 2002. The similar behaviour of the m_{var} light curves on timescales of 1-2 hours is evident in BVR (and possibly in U) filters.

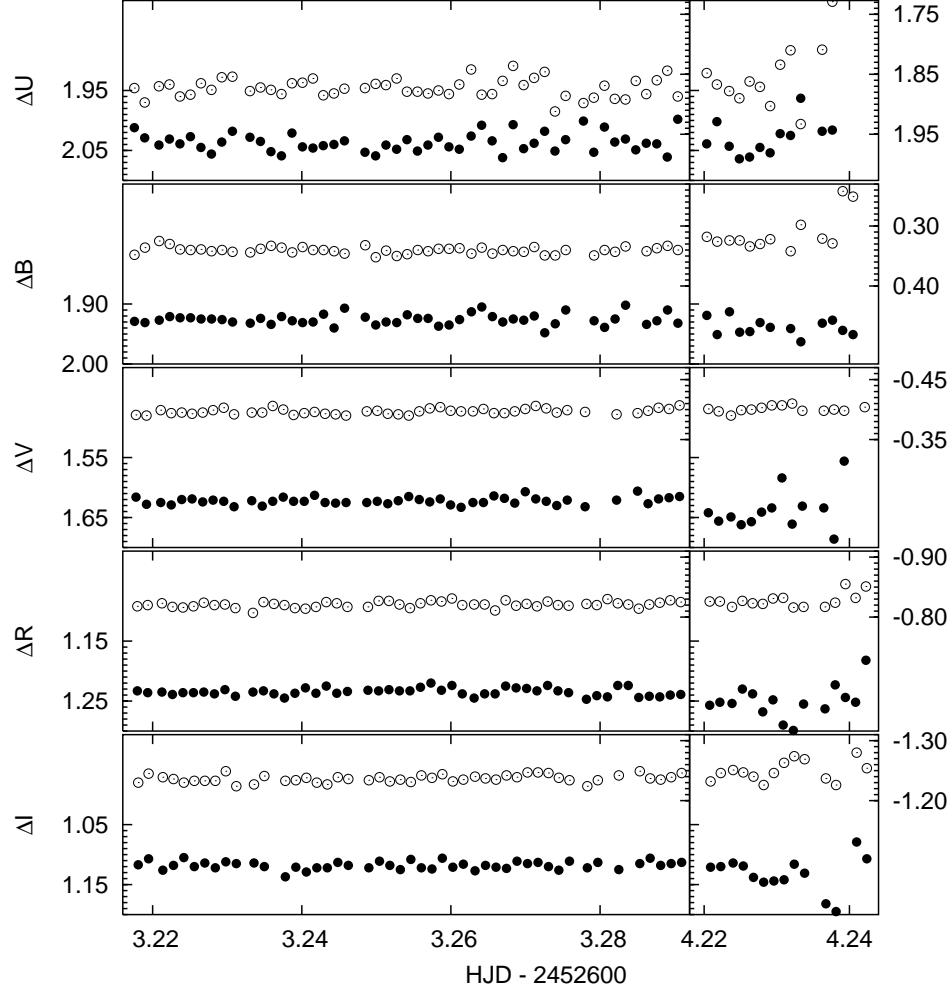


Figure 2: The differential light curves m_{var} (dots) and m_{comp} (open circles) for V471 Per on 24 and 25 November 2002.

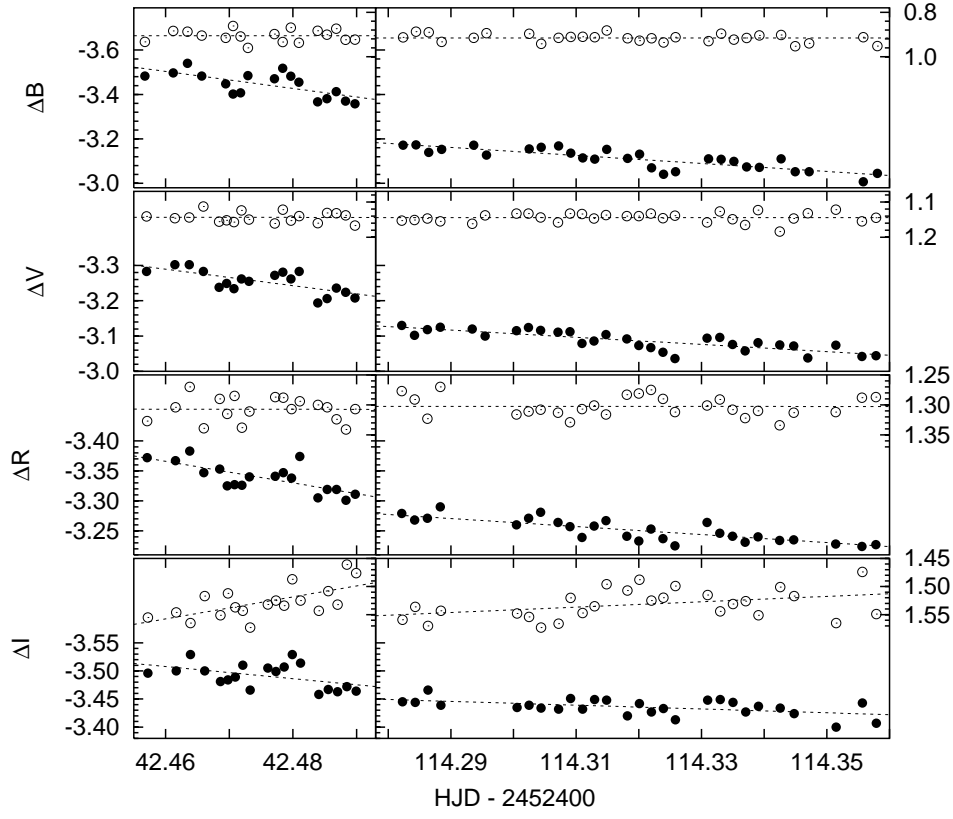


Figure 3: Differential light curves m_{var} (dots) and m_{comp} (open circles) for RS Oph obtained on 16 June and 27 August 2002. Dashed lines show the linear trends.

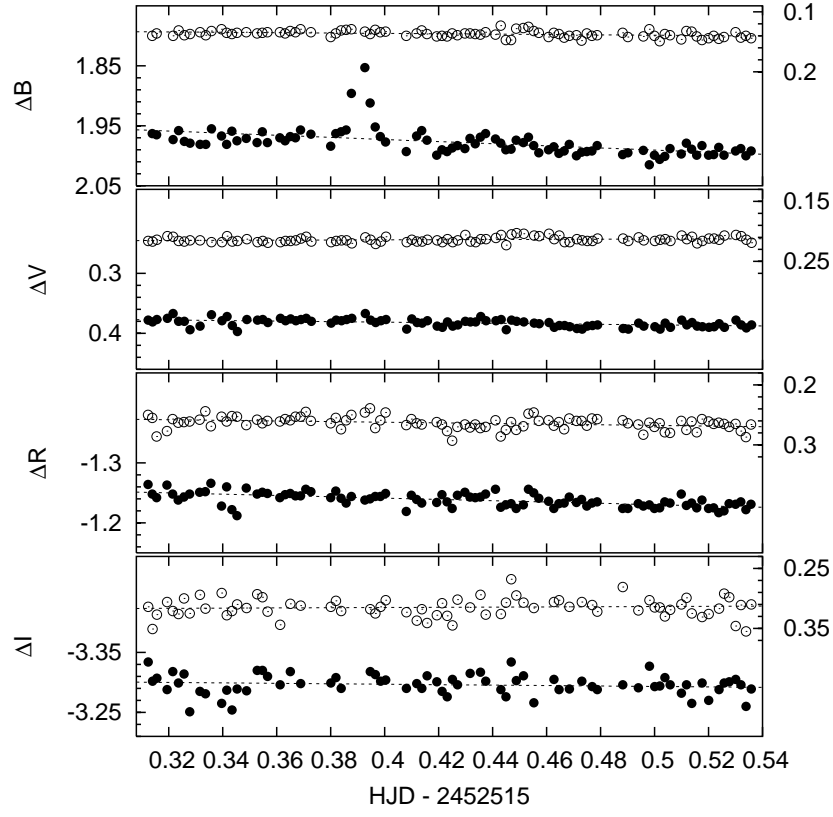


Figure 4: Differential light curves m_{var} (dots) and m_{comp} (open circles) for V627 Cas obtained on 28 August 2002. The flickering-like flare is seen only in B . Dashed lines show the linear trends.

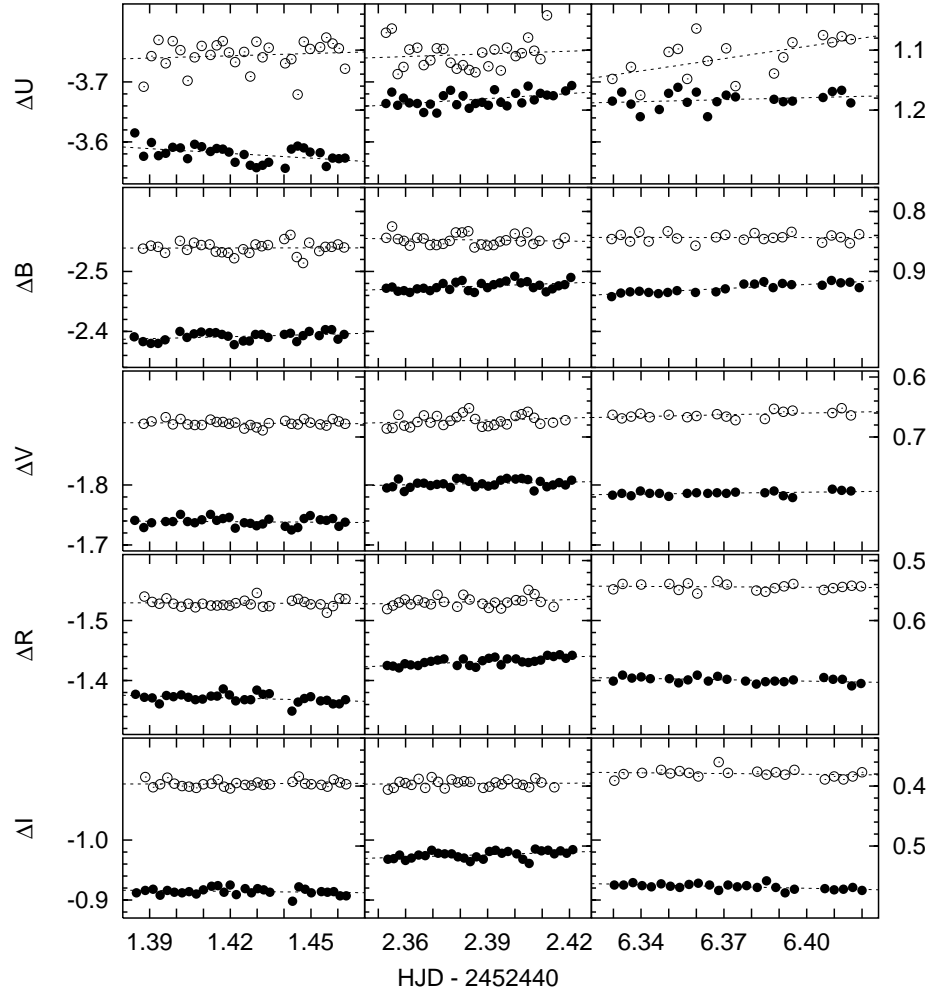


Figure 5: The differential light curves m_{var} (dots) and m_{comp} (open circles) for V886 Her on 15,16 and 20 June 2002. Dashed lines show the linear trends.

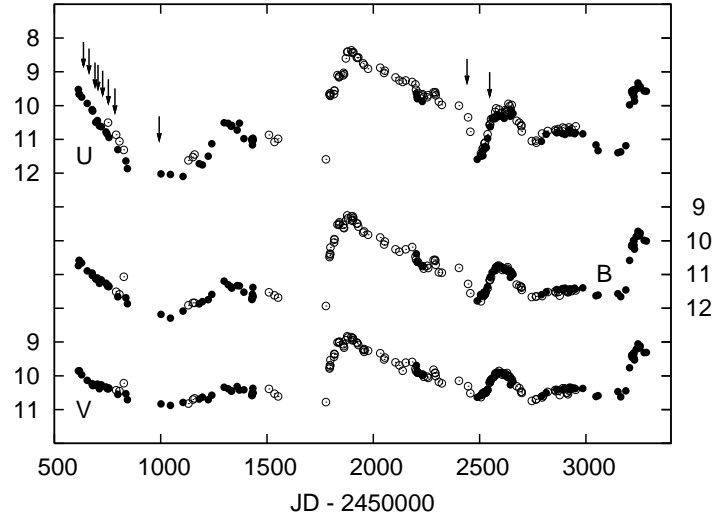


Figure 6: The UB light curves of Z And during 1997-2004 collected by Skopal *et al.* (2002,2004) (open circles) and by Mikołajewski & Gałan (in preparation) at Torun Observatory (dots). The arrows on the left indicate the moments of Sokolowski & Bildsten (1999) *B* observations. The arrow in minimum \sim JD 24501000 indicates the absence of rapid variations. The two last arrows around JD 24502500 mark the dates of our *UBVRI* data.

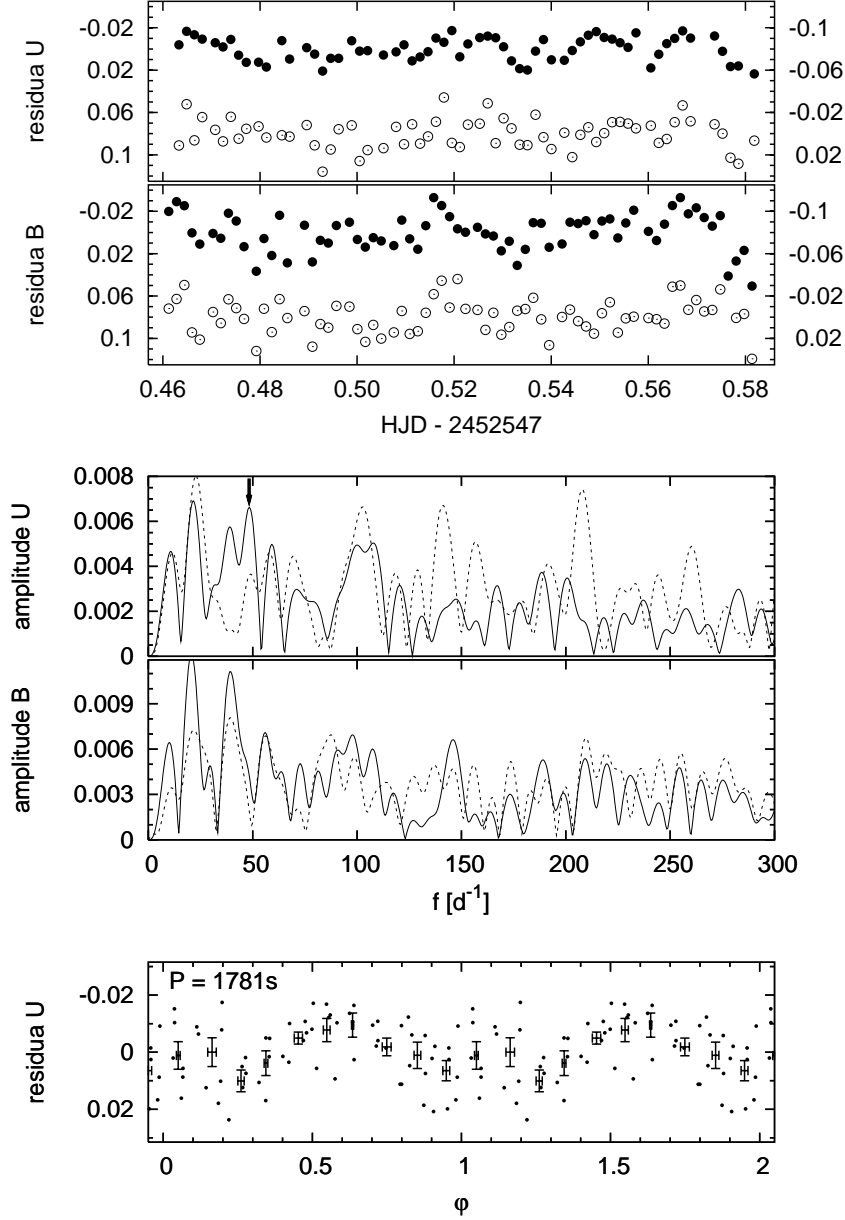


Figure 7: The 29 minutes oscillations in Z And on 29 September 2002. Top: U and B instrumental magnitude residuals of Z And (dots and left scale) and of the brighter comparison star (open circles and right scale). Middle: Power spectra of the UB residuals for Z And (solid line) and the comparison star (dashed line). The arrow points the frequency corresponding to the 29 minutes period. Bottom: U residuals folded with this period in 0.1 phase bins, with corresponding error bars and individual observations (points).

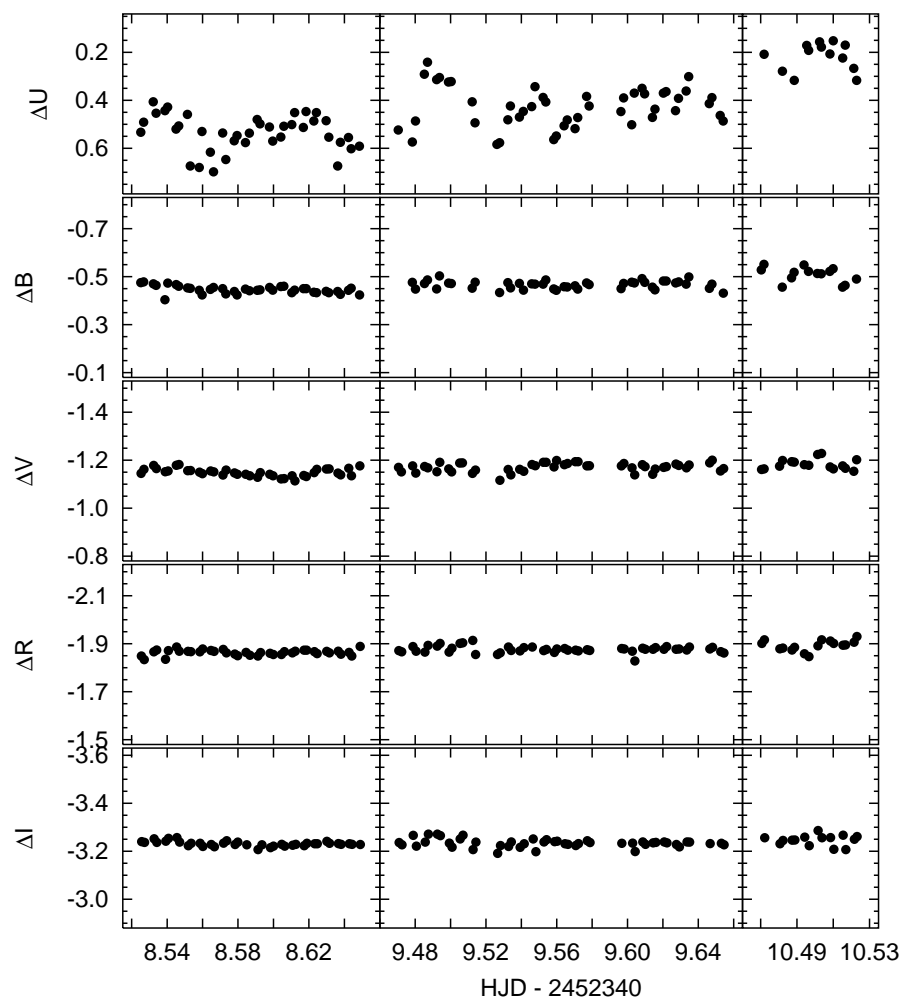


Figure 8: The differential light curves m_{var} for T CrB on 14, 15 and 16 March 2002. Significant brightness variations are seen only in U .

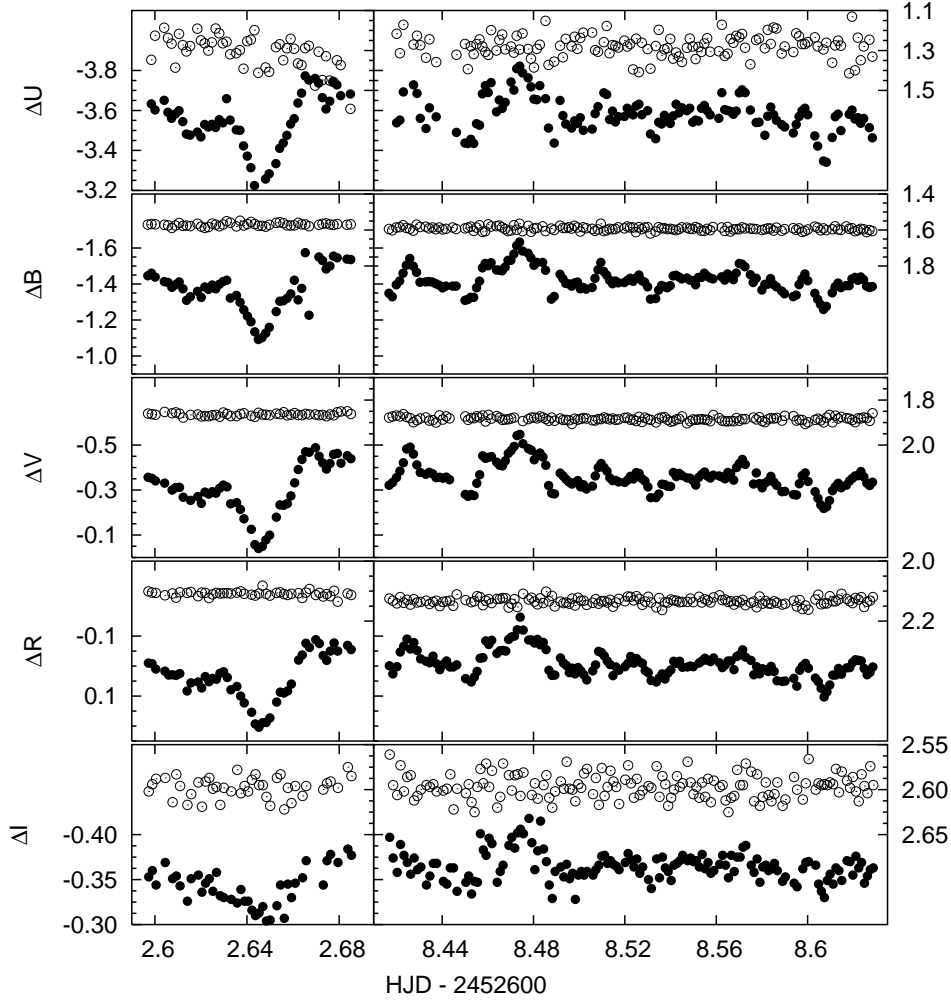


Figure 9: Differential light curves m_{var} (dots) and m_{comp} (open circles) for MWC 560 on 23 and 29 November 2002.

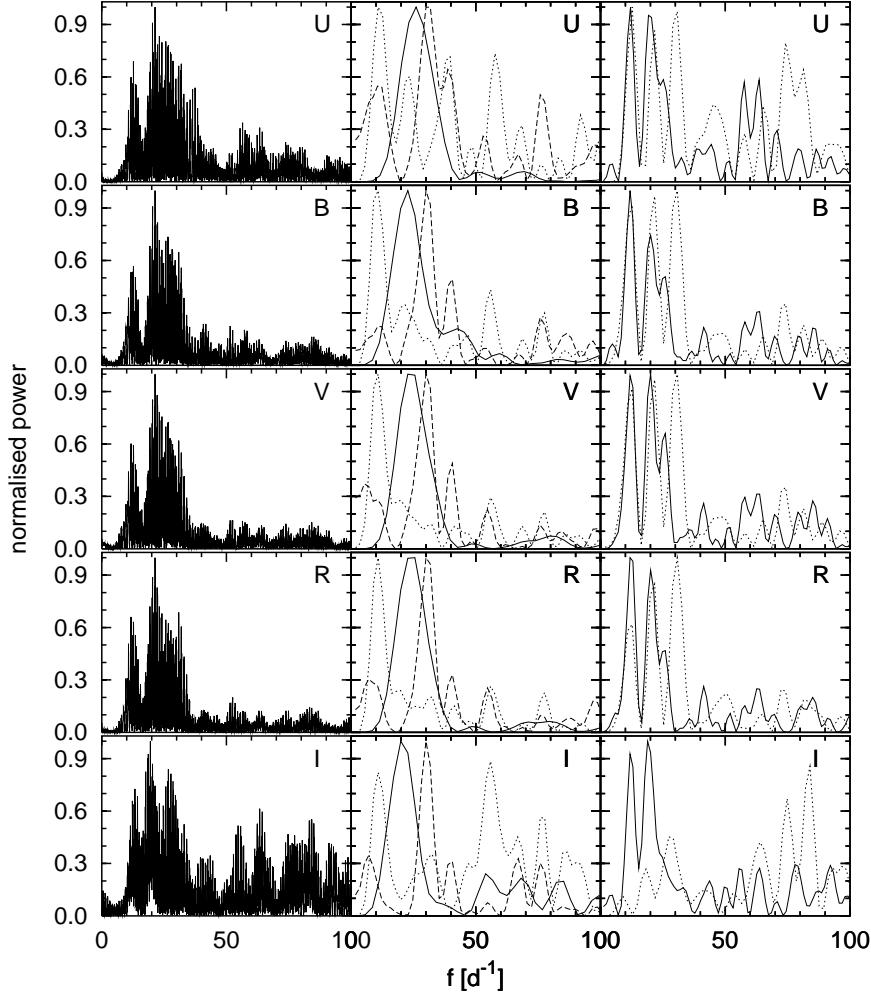


Figure 10: Normalized power spectra of the differential light curves of MWC 560. Left panel: power spectra of all the data obtained in November 2002. The strong peaks at frequencies 11.64, 20.37 and 30.14 d^{-1} correspond to periods ~ 2 hours, ~ 70 , ~ 50 minutes, respectively. Middle panel: power spectra of data obtained on 23 (solid), 24 (dashed), and 25 (dotted) November 2002. Right panel: power spectra of data obtained on 29 (solid) and 30 (dotted) November 2002.

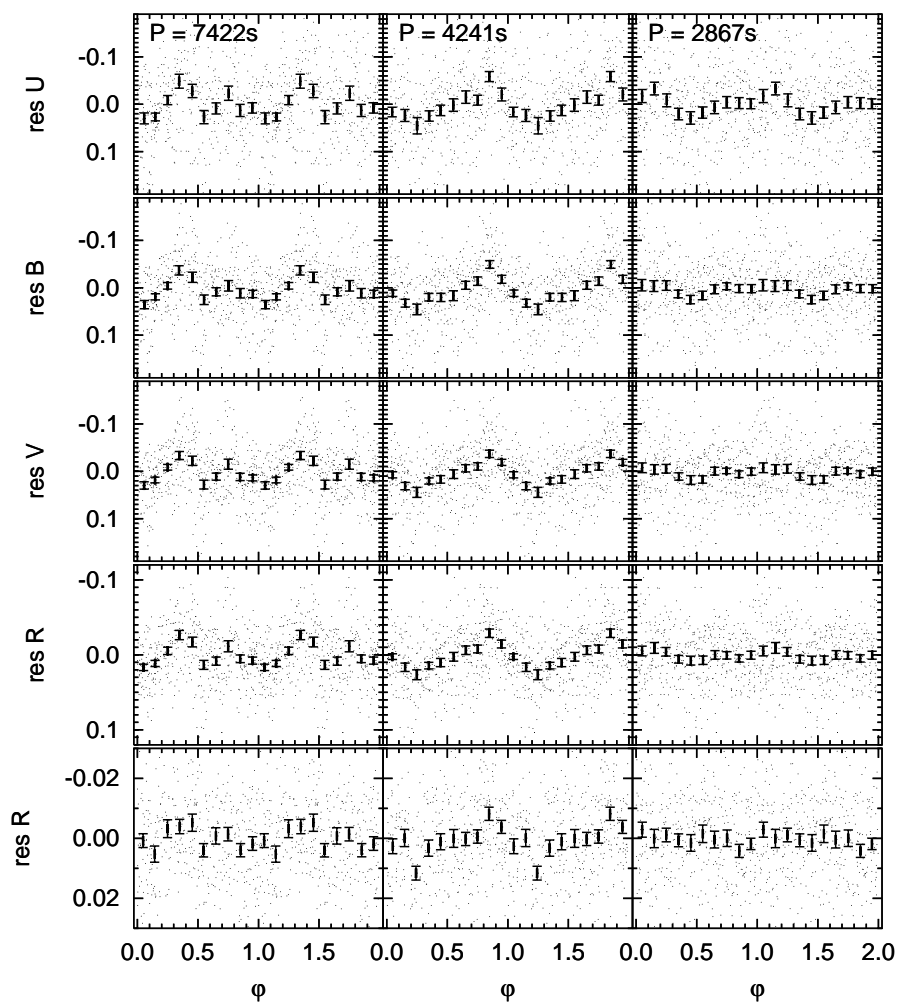


Figure 11: MWC 560 differential light curves folded with the periods found: 7422 sec (~ 124 min), 4241 sec (~ 70 min), 2867 sec (~ 48 min). The November 2002 data were also averaged into 0.1 phase bins. The bars show the rms of averaged magnitude in each bin.

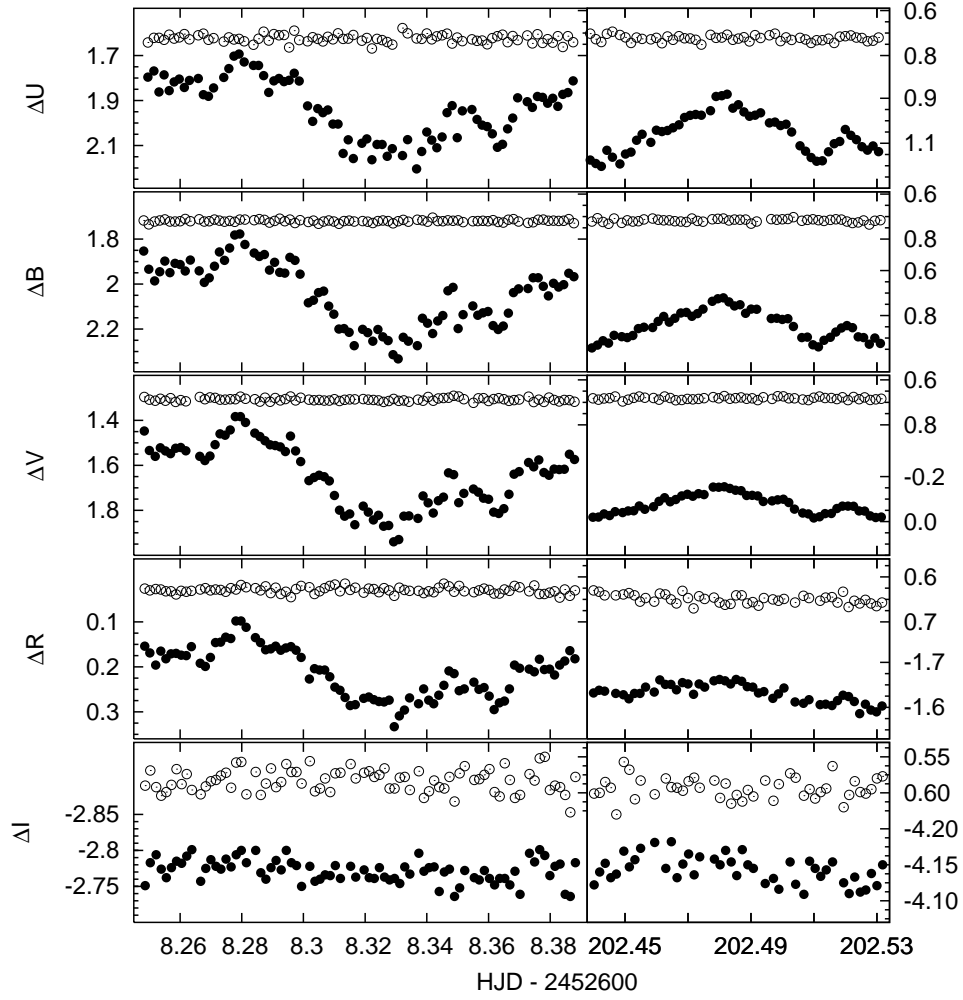


Figure 12: Differential light curves m_{var} (dots) and m_{comp} (open circles) for V407 Cyg on 29 November 2002 and 11 June 2003. In June 2003 the Mira companion was in maximum and V407 Cyg was much brighter (the bottom magnitude scale on the right).

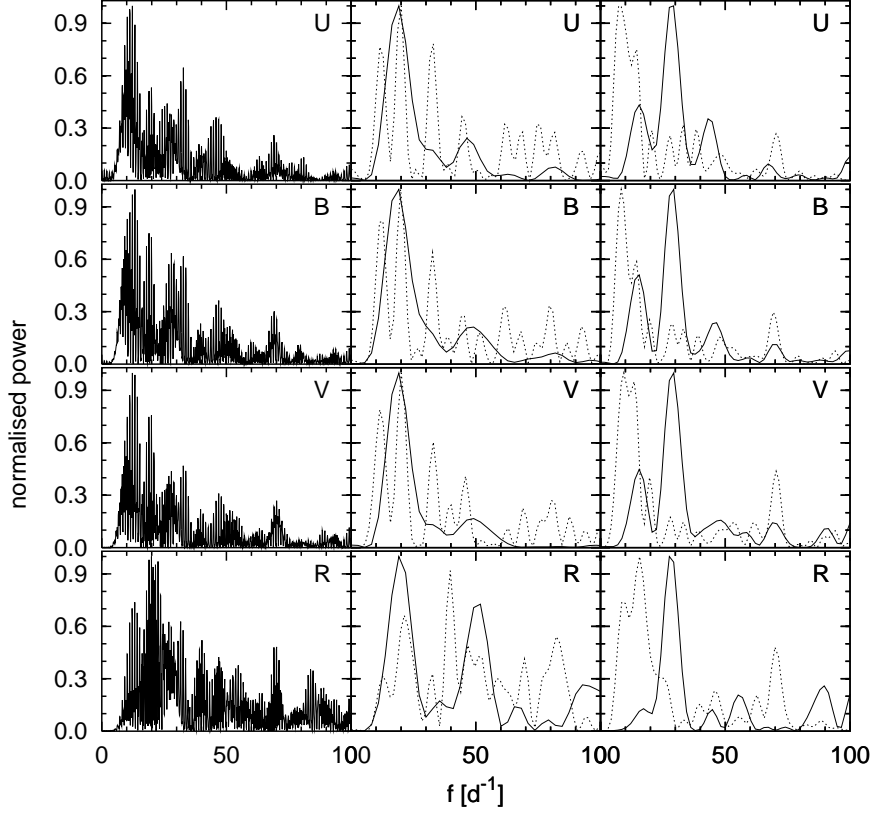


Figure 13: Normalized power spectra of V407 Cyg differential light curves. Left panel: power spectra of combined data set of the four consecutive nights in June 2003. The strong peaks at frequencies 12, 20 and $32d^{-1}$ correspond to periods ~ 2 hours, ~ 72 , ~ 45 minutes, respectively. Middle panel: power spectra of data obtained on 11 (solid) and 12 (dotted) June 2003. Right panel: power spectra of data obtained on 13 (solid) and 14 (dotted) June 2003.